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RESTRICTED DATA

Advanced Transportation System Studies

Technical Area 3

Alternate Propulsion Subsystem Concepts
NAS8-39210
DCN 1-1-PP-02147

Interim Final Report
DRs – 4, 5, 6
Volume III – Program Cost Estimates

April 1993

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Rockwell International
Rocketdyne Division

IA3-0412

Table of Contents

Introduction

This is Volume III of the Final Report covering the first year's efforts under a NASA NRA – NAS8-39210, Advanced Transportation Systems Studies, Technical Area 3 (TA3), Alternate Propulsion Subsystem Concepts. There are three other Technical Areas contracted under the NRA. TA3 is managed through MSFC/PD with Bob Nixon as project manager. The contractor team is led by Rocketdyne with Thiokol and Workingsolutionz Software as team members. The contract is a one year contract, funded at $692K, with two one year options with nominal funding of $350K for the second year and ~$1M for the third year.

The contract started on 6 April 1992, had an orientation meeting at MSFC on 29 April, its first study review on 17 June, its second study review on 1-2 October 1992, and its final review of the first year's efforts on 17 March 1993. Briefing books for each of the reviews were submitted and are available through MSFC/PD.

The objective of the contract is to provide definition of alternate propulsion systems for both earth-to-orbit (ETO) and in-space vehicles (upper stages and space transfer vehicles). For such propulsion systems, technical data to describe performance, weight, dimensions, etc. will be provided along with programmatic information such as cost, schedule, needed facilities, etc. Advanced technology and advanced development needs will be determined and provided.

A propulsion system database is also being developed which will be capable of including the systems examined under TA3 and any other existing or conceptual propulsion systems.

The contract results are reported in three parts:

Volume I – Executive Summary which overviews each of the contract tasks giving its objective, main results, and conclusions;

Volume II – Final Report which references the individually delivered detailed Task reports (the detailed results are in the separate Task reports, not in Volume II) and fulfills the requirements of a place to report DRs 8 (Computer Aided Design Graphics and Analysis Data Documentation and Transfer) and 9 (New Technology Report), neither of which had any activity to report this year;

Volume III – Program Cost Estimates (this volume) which contains DRs 5 (Work Breakdown Structure (WBS) and WBS Dictionary) and 6 (Program Cost Estimates Document).

Technical Discussion

The Alternate Propulsion Subsystem Concepts contract had five tasks defined for the first year. The tasks were: F-1A Restart Study, J-2S Restart Study, Propulsion Database Development, SSME Upper Stage Use, and CERs for Liquid Propellant Rocket Engines.

The two restart studies, F-1A and J-2S, generated program plans for restarting production of each engine. Special emphasis was placed on determining changes to individual parts due to obsolete materials, changes in OSHA and environmental concerns, new processes available, and any configuration changes to the engines.

The Propulsion Database Development task developed a database structure and format which is easy to use and modify while also being comprehensive in the level of detail available. The database structure included extensive engine information and allows for parametric data generation for conceptual engine concepts.

The SSME Upper Stage Use task examined the changes needed or desirable to use the SSME as an upper stage engine both in a second stage and in a translunar injection stage.

The CERs for Liquid Engines task developed qualitative parametric cost estimating relationships at the engine and major subassembly level for estimating development and production costs of chemical propulsion liquid rocket engines.

Of these tasks, the F-1A Restart Study, the J-2S Restart Study, and the SSME Upper Stage Use task produced estimated cost and planning data for proposed new project/program starts.

Advanced Transportation System Studies

Technical Area 3

Alternate Propulsion Subsystem Concepts
NAS8-39210
DCN 1-1-PP-02147

Work Breakdown Structure (WBS) and WBS Dictionary
DR-5

April 1993

Table of Contents

List of Figures

Work Breakdown Structure

The work breakdown structure used for cost predictions is shown in Figure 1.

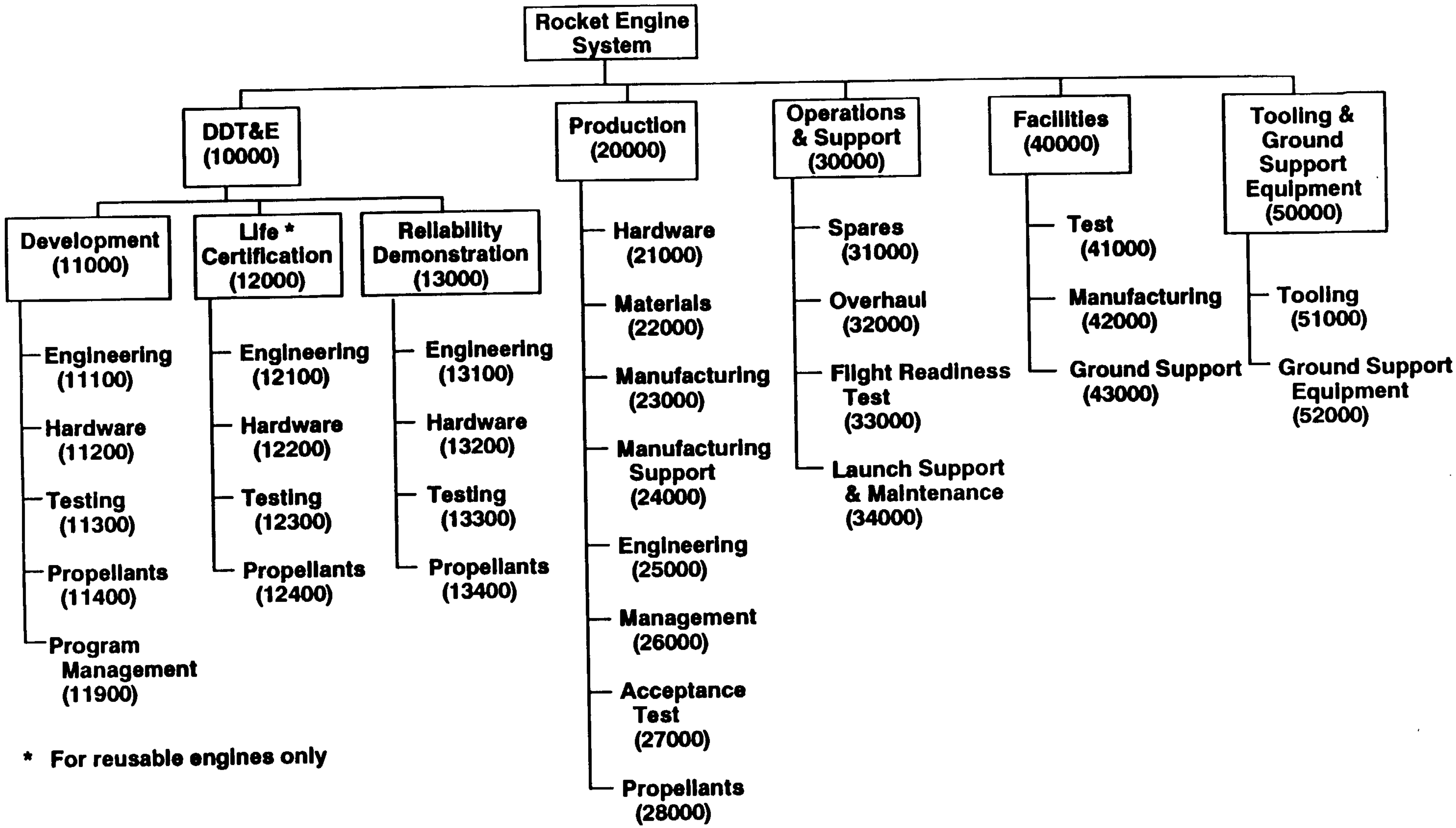


Figure 1. Work Breakdown Structure

TA3-0419Fig

WBS Dictionary

10000 – DDT&E. The total non-recurring effort of design, development, testing and evaluation is directed to developing a new, or redeveloping a previously existing, rocket engine system. Under rocket engine system, the entire rocket engine is understood up to the vehicle interface. It includes provisions for supplying propellant tank pressurants and thrust vector control devices.

11000 – Development. That part of the DDT&E which is concerned with the development of the engine, but excluding any certification or demonstration activities.

11100 – Engineering. The requirements definition, design and analysis effort of component and engine system development.

11200 – Hardware. The component and engine system hardware required for the testing part of the development effort.

11300 – Testing. The testing of parts, components and engine systems. It includes laboratory testing, component and subsystem testing (e.g., turbopumps and combustion devices) by coldflow or hot fire tests and static hot fire testing of the engine system at sea level and altitude conditions. Includes test engineering, test procedure development and test evaluation.

11400 – Propellants. All propellants and other consumables required for the engine development program, excluding the certification and demonstration processes.

11900 – Program Management. All program management, project management, data collection, handling and submittal activities, documentation and cost/schedule/performance tracking to fulfill internal and customer requirements. Covers the entire DDT&E process including certification and demonstration.

12000 – Life Certification. The certification process for determining that the specified engine life requirements are fulfilled. Applicable only to reusable engines with specified certification requirement.

12100 – Engineering. All engineering redesign/analysis activities related to the life certification process.

12200 – Hardware. Component and engine system hardware necessary for performing the life certification testing; e.g., two certification test engines and one spare (SSME).

12300 – Testing. Component and engine system hardware necessary for performing the life certification testing; e.g., two certification test engines and one spare (SSME).

12400 – Propellants. All propellants and other consumables (e.g., for seal purges and engine drying) required for the life certification process.

13000 – Reliability Demonstration. The reliability demonstration for determining by testing that the specified engine reliability and confidence level requirements are fulfilled. Applicable only to engines with reliability specifications to be demonstrated (e.g., F-1, J-2, but not SSME).

13100 – Engineering. All engineering redesign/analysis activities related to the reliability demonstration process.

13200 – Hardware. Component and engine system hardware necessary for performing the reliability demonstration testing (usually several engines, dependent on engine design life).

13300 – Testing. All engine system testing required for the reliability demonstration testing.

13400 – Propellants. All propellants and other consumables required for the reliability demonstration process.

20000 – Production. Recurring costs to produce engine systems, excluding development engines.

21000 – Hardware. inished or semi-finished hardware required for production engines. Includes subcontracted components with supplier costs, wrap factors and fee to the engine contractor.

22000 – Materials. All raw materials (e.g., sheet, bar stock) required for manufacturing of production engines.

23000 – Manufacturing. Touch or hands-on labor for manufacturing production engines.

24000 – Manufacturing Support. Manufacturing support services: (1) support to fabrication and assembly (e.g., recurring tooling, shop liaison); (2) material support (e.g., procurement, receiving inspection); (3) level of effort support (e.g., system safety, quality control); (4) fixed expenses (e.g., acceptance test support, facility test support).

25000 – Engineering. Engineering support to manufacturing.

26000 – Management. Production management and business management related to manufacturing.

27000 – Acceptance Test. Receiving, inspection, engine installation in test stand, checkout, hot-fire testing, post test inspection, engineering support and data reduction.

28000. – Propellants. All propellants and other consumables required for acceptance testing of an engine system.

30000. – Operations & Support. All operations, support and logistics activities connected to the flight engine line in support of launch activities.

31000 – Spares. Spare production engines held in inventory as a contingency for potential engine/launch vehicle problems.

32000 – Overhaul. Overhaul of recovered reusable engines for minor problems (performed at launch facility) or major problems (performed at depot/contractor.

33000 – Flight Readiness Test. Hot fire testing of multiple new engines as an engine cluster installed in the vehicle to ensure proper interfacing between engines and vehicle.

34000 – Launch Support & Maintenance. Support of engine/vehicle mating, system integration, checkout and propellant loading. In addition, mission analysis (flight evaluation) and engineering support for anomaly resolution. Receiving inspection and checkout, engine preparation, Ground Support Equipment (GSE) support. Logistics support, training, facility support, management and administration.

40000 – Facilities. Construction of new, or modification of existing facilities required for the development, production and operation of engine systems.

41000 – Test. Construction of new/modification of existing static test stand facilities.

42000 – Manufacturing. Construction of new/modification of existing production facilities for manufacturing of engine systems.

43000 – Ground Support. Construction of new/modification of existing ground support facilities at the engine contractor or launch site.

50000 – Tooling & Ground Support Equipment. All tooling and GSE required to manufacture and operate engine hardware.

51000 – Tooling. Tooling required to manufacture development and production engine/component hardware.

52000 – Ground Support Equipment. GSE to handle, transport, check out, install engine/component hardware.

Advanced Transportation System Studies

Technical Area 3

Alternate Propulsion Subsystem Concepts
NAS8-39210
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Program Cost Estimates Document
DR-6

April 1993

Table of Contents

List of Figures

Introduction

Three of the tasks performed during the first year produced estimated cost and planning data for proposed new project/program starts: the F-1A Restart Study, the J-2S Restart Study, and the SSME Upper Stage Use task. The cost and schedule information is included in the individual detailed study Task Reports and is repeated here.

F-1A Restart Study

Rocketdyne and NASA's F-1 engine completed its production run in 1969 after delivery of 98 units, 65 of which were flown on the Saturn V launch vehicle with 100% success. Nearly 255,000 seconds of hotfire testing was accumulated on the production engines and 56 equivalent development engines during the program. Development efforts included the design, analysis and testing of an F-1A engine with the capabilities of 1800 Klb thrust and of throttling as well as reduced production and operational costs. This knowledge and experience provides the foundation for a 1990's F-1A.

Figure 1 shows the overall context in which the F-1A Restart task of this NRA was performed. It was only one part of a larger effort needed to assess the restart of the F-1A.

The F-1A Restart Program is based on a multi-phase, incrementally funded plan, which when fully executed, will provide the technical and programmatic foundation necessary to support a NASA decision on F-1A production. The initial feasibility evaluation effort was performed by Rocketdyne in 1990-1991, using discretionary resources. This effort was targeted at assessing the availability, completeness, quality and usefulness of F-1/F-1A documentation, hardware, tooling, supplier, facility, and personnel resources. This information along with mission planning analysis, customer requirements input, and Rocketdyne's recent ELV Program restart experience, was used to assess the potential effectiveness and viability of the F-1A engine in a 1990's booster application. Rocketdyne's conclusion at the completion of this effort was that a customer need did exist, and that, indeed, a sufficient "critical mass" of F-1A knowledge, experience and hardware assets was available to warrant further, more detailed investigation of the feasibility of an F-1A Production Restart Program.

Phase A of the Restart Program Plan was formulated to address in detail, the configuration, manufacturing, and test issues associated with an F-1A production restart, so that detailed program schedule and cost estimates could be developed.

The effort funded in this NRA focused on that portion of Phase A that would refine the requirements for a 1990's F-1A. The remaining Phase A effort consists of two parts. The first would prepare detailed Manufacturing and Test Plans, and prepare refined program cost and schedule estimates. The second part is an effort in which Rocketdyne would support the return, disassembly, and evaluation, at MSFC, of an F-1 resource engine.

Phase B of the program would focus on selected technology demonstrations, hardware assembly efforts, and ultimately an engine hotfire demonstration test.

The cost elements comprising total engine cost for contractor and government are indicated in Figure 2. The costs are based on a five-engine development/certification program (the details of which are shown on Figures 3 and 4) and delivery of 72 flight engines produced at the Rocketdyne Canoga facility. The TBD costs depend on: type of contract, location and number of engine and component test facilities, stage testing requirements, and Rocketdyne flight support involvement.

Figure 5 shows the restart (development and certification) portion of the F-1A program. The schedule represents a moderately paced program to support certification of the engine in four years. Engine test cost and schedule to complete certification, is based on a 5 engine, 85 test program, which will accumulate 9,250 seconds of duration. The engines designated for the program are one resource engine (a residual F-1 flight spare), and four engines fabricated on the new F-1A production line, which include: one development engine, one verification engine, and two certification engines. Additional verification of engine reliability will be obtained, prior to the first flight, by the completion of the production acceptance and stage testing of the first flight set plus any other engines acceptance tested prior to that time.

To decrease schedule risk, it is recommended that $500K be authorized to support procurement of long lead material, primarily castings and thrust chamber tubes, six months prior to authority to proceed.

To provide an early demonstration of F-1A Restart progress, a turbopump/gas generator throttling demonstration test, using residual F-1/F-1A hardware can be

conducted on a component test stand. Funding of $2M prior to authority to proceed has been planned within the component testing task to provide engineering and manufacturing support for this activity.

Facility costs are not reflected in this figure, since the test facility(ies) have not yet been selected.

The overall (restart and production) schedule is shown in Figure 6. Previously, Rocketdyne projected an F-1A Restart program leading to a first flight 5 years after authority to proceed. The cost of the non-recurring portion of the program, through single engine certification, was estimated to be $315M, in constant FY'92 dollars, and assuming manufacturing and assembly performed at the Rocketdyne Canoga Park facility. This breaks down into $125M for manufacturing facilities activation and $190M for development and verification testing. Excluded from these costs are: facility costs, contractor fee, government support costs, vehicle dependent costs, and contingency funds. These are items which depend on government decisions, such as: type of contract, location and number of engine test facilities, and stage testing requirements and location.

The recurring cost estimate of $1080M represents delivery of 72 engines at an average cost of $15M per engine, over a 5 year period. Deliveries commence four years after authority to proceed, at a peak rate of 16 engines per year. The major factors that impact the engine production costs are total quantity, delivery rate, and the degree of factory automation.

These F-1A Restart non-recurring and recurring cost estimates were examined at the completion of this NRA study to determine if any changes were appropriate, based on the study results. The study findings indicated that there were no program activities overlooked that would adversely affect the cost estimates, and that those cost elements that were included, were properly estimated, based on the top down estimating approach used. The study also identified a number of yet to be quantified net cost reduction opportunities. The remainder of the Phase A Restart Plan calls for the preparation of detailed Manufacturing and Test Plans which will enable the refinement of the non-recurring and recurring cost estimates for the restart of the F-1A program.

J-2S Restart Study

The J-2S (J-2 Simplified) engine was originally developed as a follow on configuration for the J-2 Saturn vehicle upper stage engine. The intent of the design was to not only provide performance upgrades to the engine but to greatly simplify the production and operation of the engine. The original J-2S effort used the same design and development team as the J-2.

The nominal vacuum thrust of the engine was 265,000 pounds while providing a specific impulse of 436 seconds with a 40:1 nozzle expansion ratio. Baseline operation was at a mixture ratio of 5.5, oxidizer to fuel, with the capability to operate at mixture ratios of 5.0 and 4.5 upon command for optimized propellant utilization during the mission. All engine interfaces were located such that the engine could be used as a direct substitute for the J-2 engine. The engine cycle was changed to a tap-off cycle to eliminate the gas generator. Throttling capability was added as an option for applications other than the Saturn Program. The engine also included a feature for low thrust operation known as "Idle Mode" which was to be used for propellant tank settling, on orbit maneuvering, and rapid engine chilldown prior to firing.

This engine system was validated with 6 flight configuration engines in 273 tests for a total operating experience of 30,858 seconds. Upon the termination of the J-2S program, the engine was ready to go into certification for flight operations.

The objectives of this NRA J-2S Restart Study were to assess what design changes would be required to reinitiate production of the J-2S engine for use as a large high energy upper stage engine, as it was designed for, or the possible use as a boost stage engine. The study was to assess design changes required to perform per the J-2S model specification, to assess manufacturing changes required due to obsolescence or improvements in state-of-the-practice, availability issues for supplier provided items, and to provide cost and schedule estimates for this configuration.

The results of the study would then provide the necessary foundation for the detailed manufacturing and test plans and non-recurring and recurring cost estimates that are needed to complete the effort to reinitiate production of the J-2S engine system.

For cost estimating of a J-2S restart program, it was assumed that the engine life requirement would be the same as the original J-2S model specification calling for 30 starts and 3,750 seconds of operation. It was also assumed that in-flight restarts would be a requirement so the engine is configured for three starts on a mission. The planning assumed that government facilities would be used wherever they were available and cost effective. A limitation placed on this planning was to limit certification to single engine configurations so that this work would not be configuration dependent. This means that additional effort would be required for clustered applications since nozzle thermal protection and main propulsion test article testing are not included. For the purpose of cost estimating, the use of Rocketdyne facilities and engine assembly were presumed which did not account for any gains to be had in colocating production and test facilities. The planning used for production restart assumed that the existing drawings and specifications would be updated rather than transferring the drawings and specifications to electronics based systems. Modifications to Rocketdyne facilities have been identified and estimated for areas where such testing would occur. Finally, the cost of the propellants were not included in the estimates since this is highly dependent on facility configuration, test program, and test location.

Figure 7 shows the non-recurring cost estimate for a J-2S restart program, development and certification. The figure shows what cost elements are included in the non-recurring cost estimate. The cost shown is for contractor effort required to achieve single engine operation certification. Estimates for flight engines are provided later in this briefing as a function of quantity produced and yearly production rate. There is no fee associated with these estimates. Estimates for clustered engine application must be tied to a specific configuration to account for thermal protection and MPT testing requirements.

Facility costs are highly dependent on location, who was conducting the work, and other factors. An estimate is provided for the refurbishment of a Rocketdyne test

facility which could perform the desired testing. Government support is not estimated nor is a contingency fund.

Figure 8 shows how a conservative engine development test plan can examine all pertinent operating points using the proposed four development engines and two qualification/certification engines. This matrix presumes that either an altitude simulation facility, similar to that previously used at AEDC, or a diffuser nozzle is available for the test program. The total tests required to perform this matrix is 210 tests for a total duration of approximately 25,000 seconds.

Four of the six engines will be tested to the model specification life of 3,750 seconds while two will undergo extended testing to 5,000 seconds. This is only a preliminary test matrix which takes a very conservative approach to verifying the flight readiness of the engine.

Figure 9 shows the schedule and yearly costs for the J-2S restart program. The program schedule assumes a go-ahead is given at the start of fiscal year 1994 with money released in mid fiscal year 1993 to initiate long lead procurement. This effort accounts for the progress made towards restart by this study. System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR) are shown taking place during the first two years of the program. Hardware fabrication is initiated at the start of fiscal year 1995 with component test preceding this by six months using existing hardware. System level testing is initiated during the last quarter of fiscal year 1996 and completing certification midway through fiscal year 1998. The delivery dates of the six development engines and the two certification engines are shown. The funding is shown on a yearly basis in constant fiscal year 1992 dollars.

Finally, Figure 10 shows the estimated production costs for the restarted J-2S. This chart shows the predicted production costs as a function of rate in units per year and total quantity produced assuming the established Rocketdyne learning curve. The three curves, from top to bottom, show first unit cost, 10 year production average unit cost, and last (or Nth) unit cost. These curves are for cost only and do not include fee or contingency.

This cost estimate is based on historical J-2S fabrication touch labor escalated to FY 1992 wrap rates at Rocketdyne's production facilities. This estimate does not account for the recommended producibility improvements listed under the producibility assessment. Effort that was beyond the scope of this study in the areas of manufacturing planning and cost estimating would be required to incorporate the results.

SSME Upper Stage Use Task

The main objective of this study was to determine if the SSME can be used in an upper stage application in which an altitude burn for earth orbital insertion and an orbital translunar injection burn may be required. The SSME currently operates and performs cut off in a space environment; however, it starts at sea level in an ambient atmosphere. Also, the current tank pressures are higher than would be desirable for an upperstage. The key goals of this study were to determine viable methods for starting the SSME in an altitude environment and restarting it in an orbital environment with minimum changes in utilization of the engine system or hardware.

A common start sequence for both altitude and orbital conditions was a key objective of the study. By maintaining a common start sequence development costs can be minimized.

The results of the study indicated that both an altitude start and an orbital start were feasible with minimal changes to the SSME engine system.

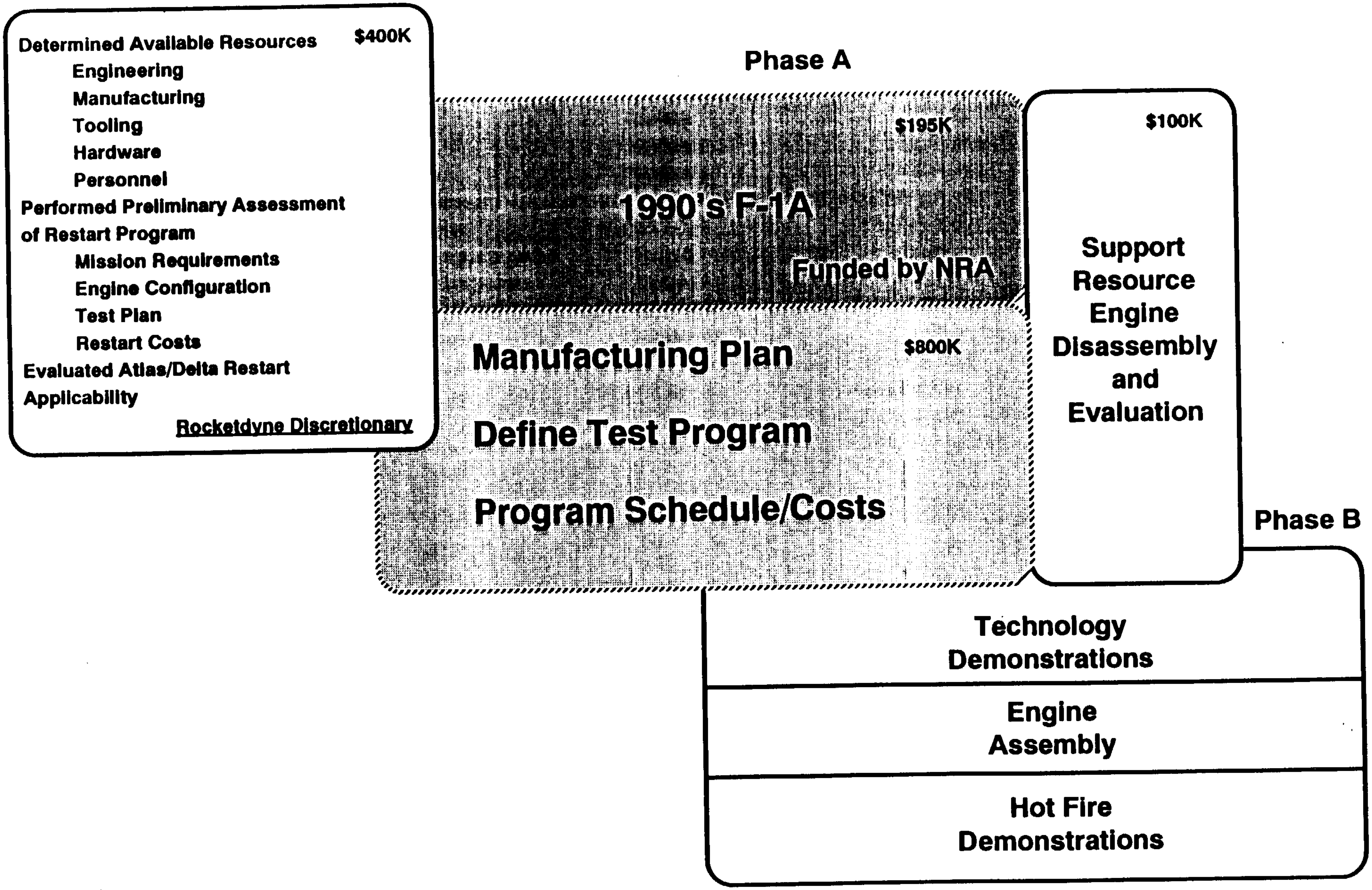
The altitude start case is especially easy, requiring only a change in the valve sequencing during start and reorificing of the ASI lines. Inlet pressures can be moderately low at 40 psia for the LOX and 32 psia for the H2.

The orbital restart case adds the need to recirculate propellant and thermal control paint (to keep the turbomachinery inlets cold to minimize the tank pressures needed), and the need to heat two small components (to maintain acceptable mixture ratios during the early part of the start). These actions allow start anytime after ~120 minutes. Earlier starts (~one hour) are also possible but would require additional component heating for mixture ratio control during the early portion of the start sequence.

The program needed, shown in Figure 11, to develop and certify the SSME for upperstage application can be accomplished with low risk and relatively low cost

compared to a new engine program. Key testing can be accomplished in a minimal cost demonstration program to provide an early understanding of the risk involved before development and certification of SSMEs for upperstage use is started.

The ground rules and assumptions which were utilized for estimating the program costs are as follows: All costs are in Fiscal Year 1992 dollars. The cost of production engines for the new vehicle is not included. The demonstration program and development program are conducted in series and transition immediately from one to another. Engine unit costs are based on a total production rate of six per year. Only minor changes, such as reorificing of igniter propellant feedlines, adding insulation/thermal control paint, reducing insulation on the nozzle, and incorporating a LOX propellant recirculation system are required. Procedural changes for the engine are assumed to be required as well. The engine used for the demonstration is upgraded and used as the first development engine. Propellant costs are not included in the cost estimate as they are typically furnished by the customer. The total program cost of $174.8 million does not include fee. The schedule assumes that one test stand at the NASA Stennis Space Center is available and that 130 tests are needed between the Arnold Engineering Development Center and SSC. Assuming production of flight engines occurs 2 1/2 years after the program is initiated, initial launch capability is viable in 5 1/2 years from program start.



TA3–0228Fig

Figure 1. F-1A Restart Program Overview

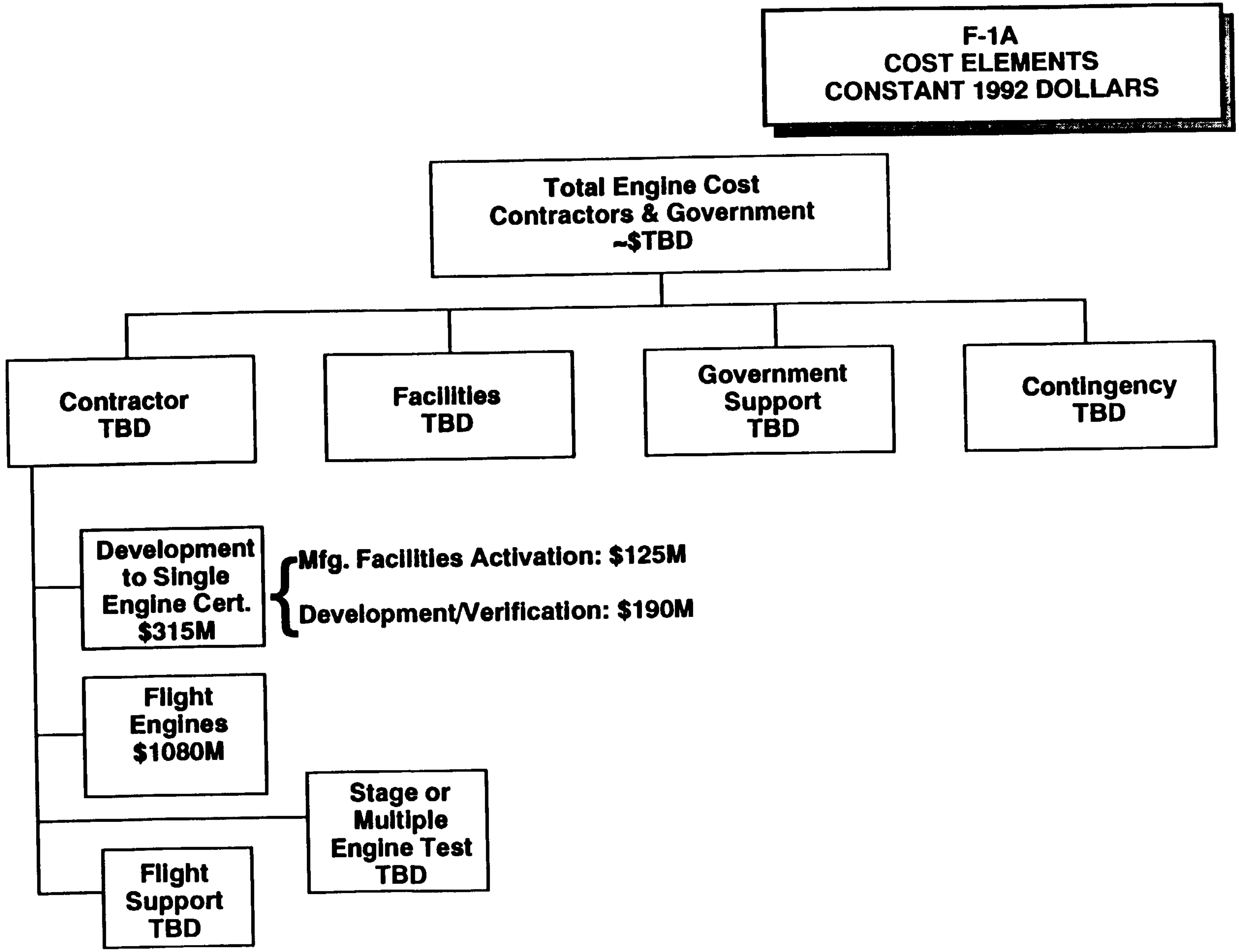


Figure 2. F-1A Restart Program Cost Elements

TA3-0230Fig

- F-1A Engine Test Plan
  - 5 Tests, 250 seconds on a Refurbished Resource F-1 Engine
  - 20 Tests, 2,250 seconds on a F-1A configuration Development Engine
  - 20 Tests, 2,250 seconds on a F-1A Verification Engine Built to Production Requirements
  - 20 Tests, 2,250 seconds on Each of Two Certification Engines
  - Additional “Backup’ Test Engine to be Built

Figure 3. F-1A Restart Verification Test Program

TA3-0416Fig

Hot Fire Test Objectives / Engine*	F-1A				
	R	D	V	C1	C2
Ignition	X	X			
Start / Cutoff	X	X			
Performance	X	X	X	X	X
Endurance / Durability		X	X	X	X
Gain Factors			X	X	X
Limits Testing		X	X	X	X
Combustion Stability	X	X	X	X	X
Throttling		X	X	X	X
Safe Shutdown	X	X	X	X	X
Thermal Environment		X	X	X	X
Gimballing			X	X	X
Flight Certification				X	X
Tests	5	20	20	20	20
Seconds	250	2,250	2,250	2,250	2,250

Total 85 Tests /
9,250 seconds

* R – Resource Engine
D – Development Engine
V – Verification Engine
C – Certification Engine

TA3–0417Fig

Figure 4. F-1A Restart Engine Test Matrix

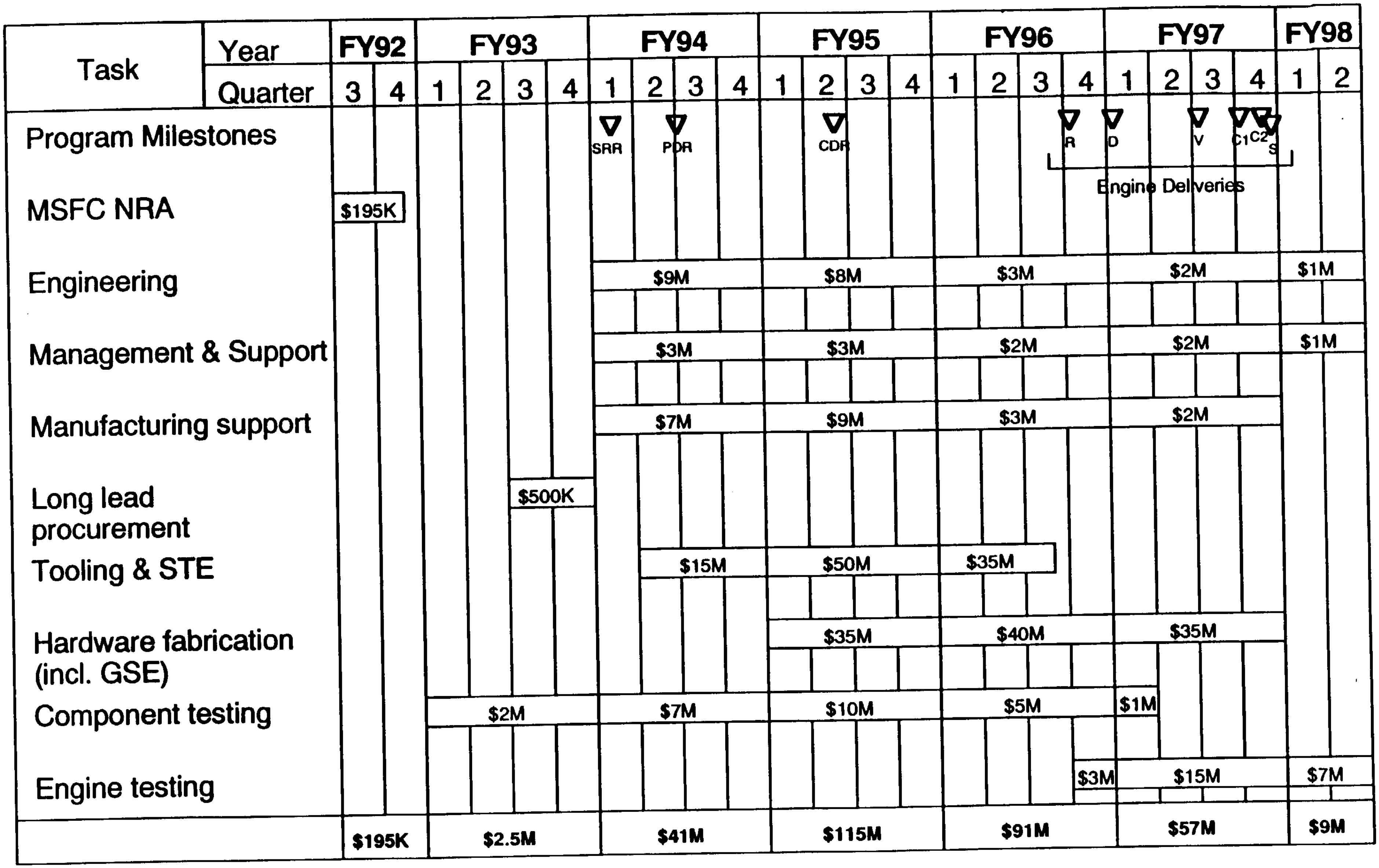


Figure 5. F-1A Restart Program Non-Recurring Cost and Schedule Constant FY92 Dollars

TA3 0229Fig

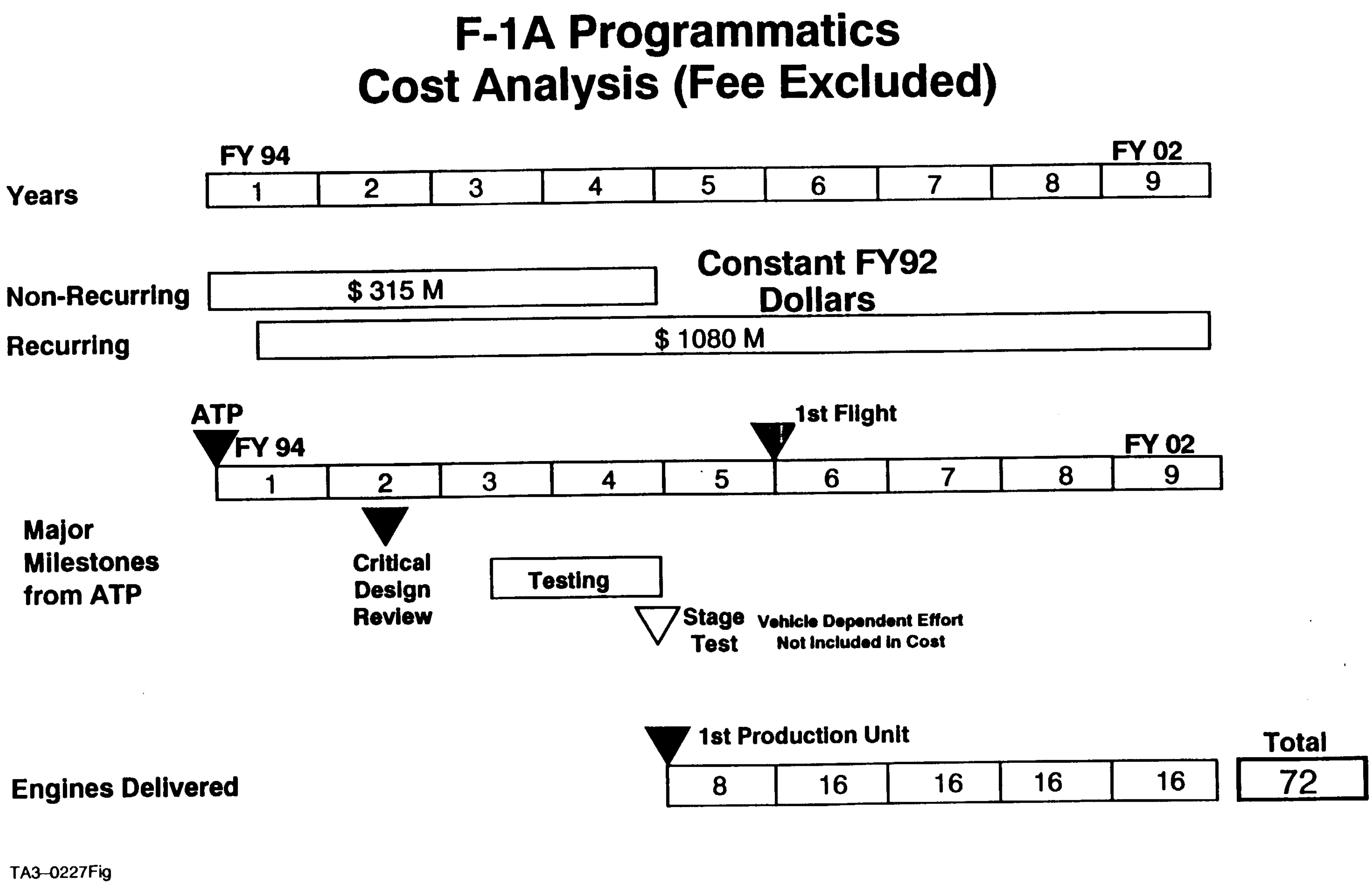


Figure 6. F-1A Restart Program Recurring and Non-Recurring Cost and Schedule

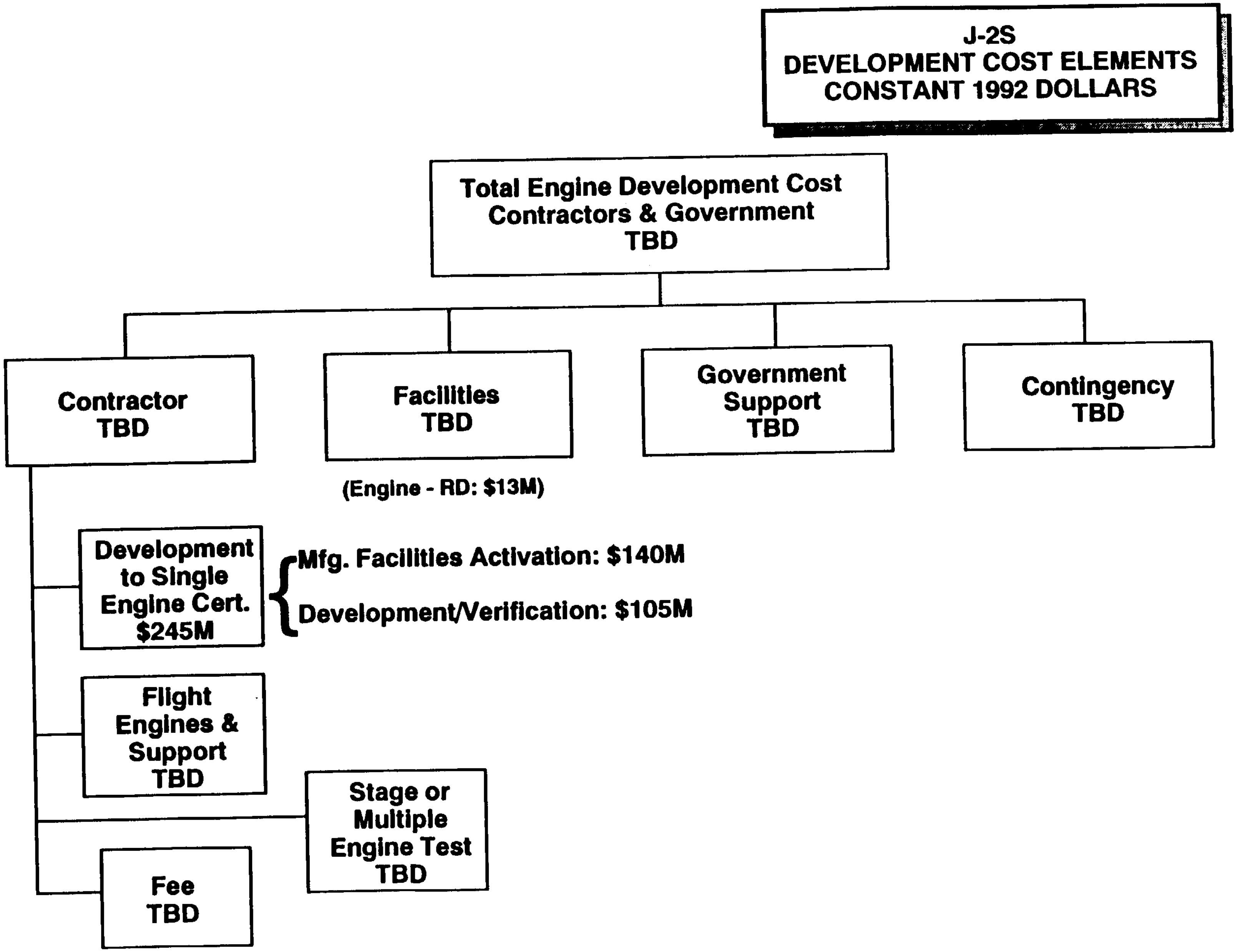


Figure 7. J-2S Restart Program Cost Elements

TA3–0418Fig

Hot Fire Test Objectives (A)	Engine 1	2	3	4	5	6
Start & Cutoff Transient	S	S	S/A	S	S	S/A
Mainstage Performance	✔	✔	S	✔	✔	S
Endurance/Durability		✔	✔	✔	✔	✔
Mixture Ratio Control	✔	✔	✔	✔	✔	✔
Idle Mode (B)	✔	✔	S/A	✔	✔	S/A
Safety Limits Testing		✔	S/A	✔	✔	S/A
Gain Factors	✔		✔	✔	✔	✔
Combustion Stability		✔		✔		
Gimbaling			S	✔	✔	S
Stage Tank Pressurization	✔		S/A	✔	✔	S/A
Start-restart Capability		✔	S/A	✔	✔	S/A
Qualification					✔	A
TESTS	30	45	30	45	30	30
SECONDS	3750	5000	3750	5000	3750	3750

(A): S – sea level or site test
A – vacuum altitude simulation

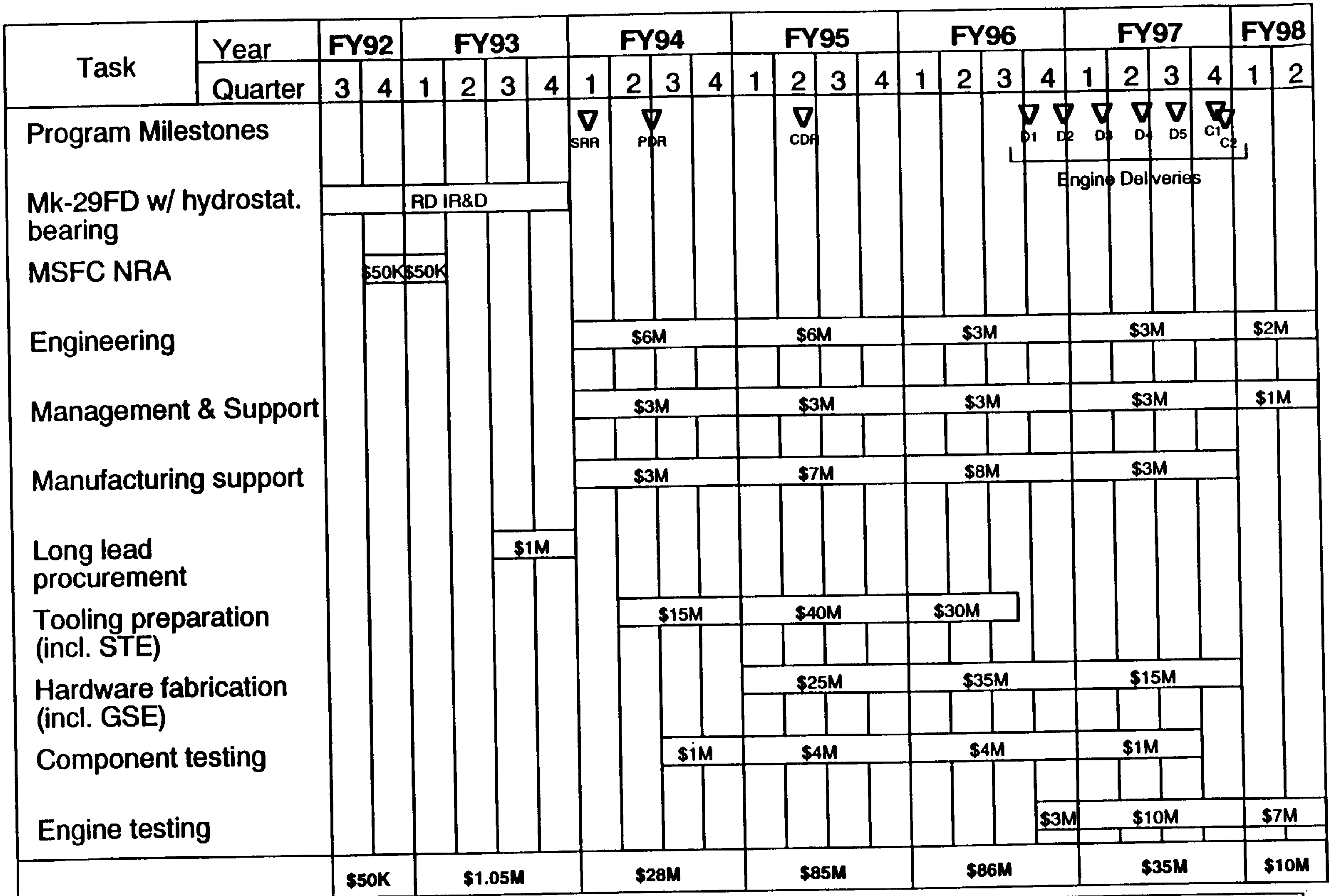
(B): T – tank head idle mode

Preliminary

210 tests
25,000 sec.

Figure 8. J-2S Restart Study Preliminary Engine Test Matrix

TA3 0400Fig



Note: Shown in constant FY92 dollars

Total Non-recurring Cost = $245M

Figure 9. J-2S Restart Program Non-Recurring Cost and Schedule

TA3-0398Fig

PREDICTED PRODUCTION COSTS
J-2S ENGINE

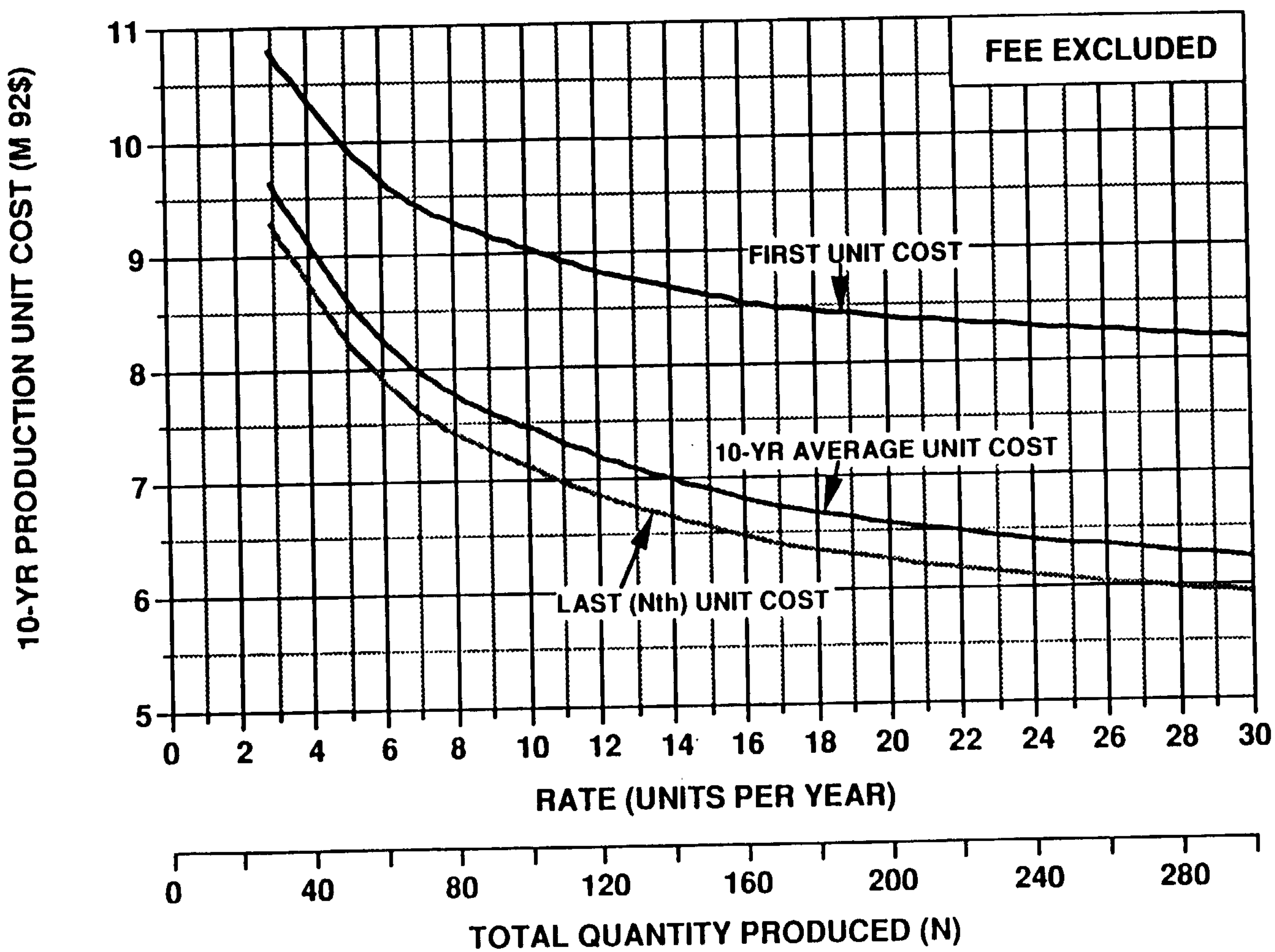


Figure 10. Predicted Production Costs — J-2S Engine

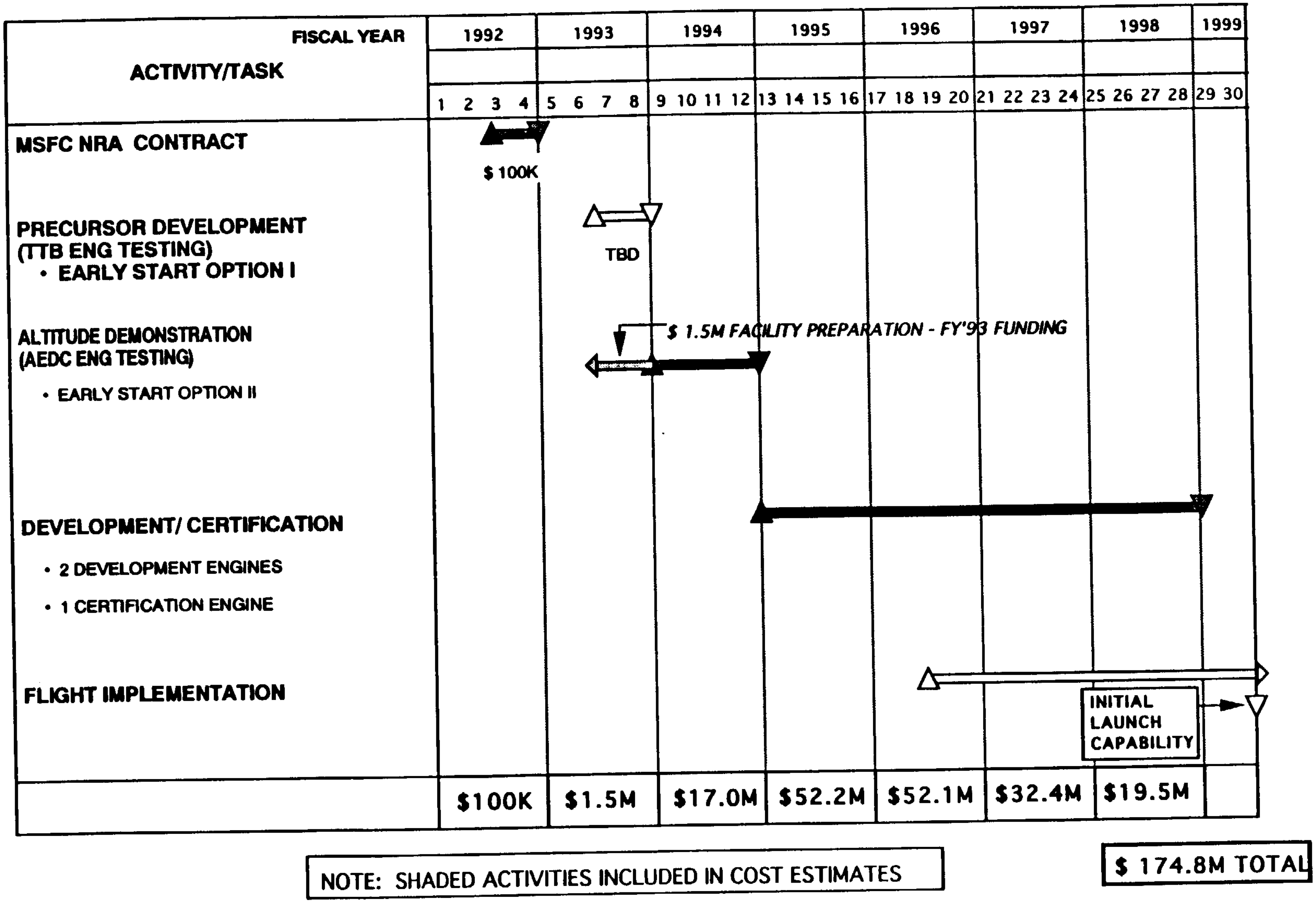


Figure 11. SSME Upper Stage Use Development Plan Cost and Schedule

TA3 0296Fig

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10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Thiokol Space Operations and Workingsolutionz Software were team members on this effort.

12a. DISTRIBUTION / AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The objective of this contract was to provide definition of alternate propulsion systems for both earth-to-orbit (ETO) and in-space vehicles (upper stages and space transfer vehicles). For such propulsion systems, technical data to describe performance, weight, dimensions, etc. was provided along with programmatic information such as cost, schedule, needed facilities, etc. Advanced technology and advanced development needs were determined and provided.

This volume separately presents the various program cost estimates that were generated under three tasks: the F-1A Restart Task, the J-2S Restart Task, and the SSME Upper Stage Use Task. The conclusions, technical results , and the program cost estimates are described in more detail in Volume I – Executive Summary and in individual Final Task Reports.

14. SUBJECT TERMS
Propulsion, Rocket Engine, F-1A, J-2S, SSME

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